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Simulation of Earth-Moon-Mars Environments for the Assessment of Organ Doses

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❖ Simulation of Space Radiation Environment

- ❖ GCR in interplanetary space[1,2] represented by GCR deceleration potential, ϕ.
- ❖ Trapped protons[3] at low Earth orbit (LEO) and the vertical cutoff rigidities for ISS orbit[4] and geomagnetic transmission factor for GCR at LEO[5].
- ❖ Statistical prediction of solar particle event (SPE) occurrences[6] and fluences as a function of mission period by a non-homogeneous Poisson process model fitted to a database of proton fluence measurements of SPEs[7].
- ❖ Calculation of Martian atmospheric shielding thickness at elevation for variable solar activities using Mars Global Surveyor data and the distribution of cosine angle.

❖ Assessment of Organ Doses

- ❖ Transport properties of the shielding materials and the astronaut's body tissues: NASA BRYNTRN[8] and HZETRN/QMSFRG code system[9,10]
- ❖ Spherical shield configurations including spacesuit and equipment room of a spacecraft as 0.3 and 5.0 g/cm^2 aluminum, respectively.
- ❖ Body shielding distribution at the sensitive organs of astronaut of computerized anatomical man (CAM) model[11]
- ❖ Acute radiation response and NASA limits analysis with organ dose estimates for mission scenarios[12,13,14].

ARR Sickness at Severity Level[12]

Severity Level	Upper Gastrointestinal Distress (UG)	Fatigability and Weakness (FW)
1	No effect	No effect
2	Upset stomach, clammy and sweaty, mouth waters	Somewhat tired with mild weakness
3	Nauseated, considerable sweating, swallows frequently to avoid vomiting	Tired with moderate weakness
4	Vomited once or twice, nauseated, and may vomit again	Very tired and weak
5	Vomited several times, including the dry heaves, severe nauseated, and will soon vomit again	Exhausted with almost no strength

Exposure limit by NASA[14]	Organ dose, Gy-Eq
30-d limit at Skin	1.5
30-d limit at Eye	1.0
30-d limit at BFO	0.25
Minimum BFO dose for ARR	0.5

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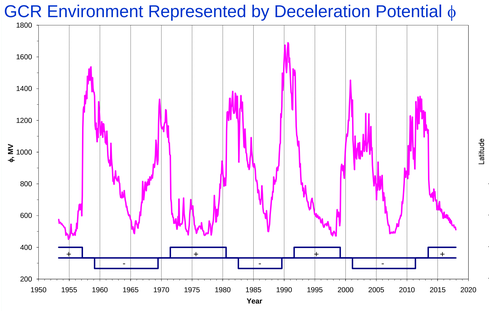
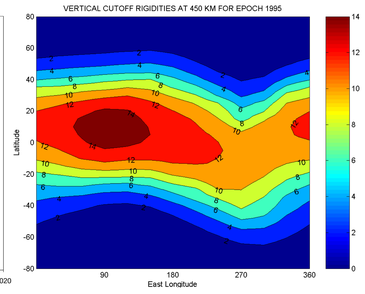
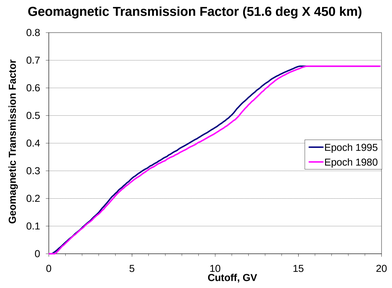
Environmental Parameters for Space Radiation Simulation

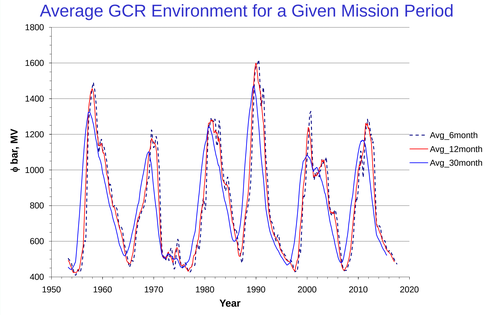
GCR Environment Represented by Deceleration Potential ϕ



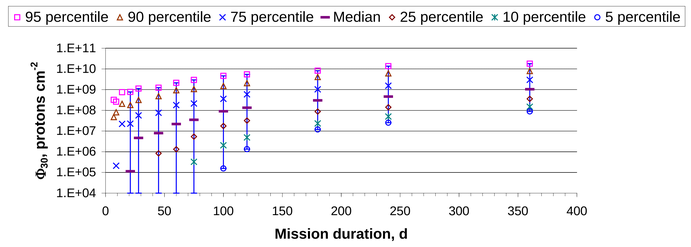




Average GCR Environment for a Given Mission Period



Simulated Distribution of SPE Fluence at 30 MeV



Environmental parameters		Mission duration 6-Month	12-Month	30-Month*
GCR deceleration parameter (ϕ), MV	Solar minimum	428	428	428
	Median solar activity	735	743	773
	Solar maximum	1100	1100	1100
SPE fluence (Φ_{30}), p/cm^2	Median level	1.39x10^8	9.74x10^8	5.26x10^9
	August 1972 SPE	8.10x10^9	8.10x10^9	8.10x10^9
	Upper 95% level	1.08x10^{10}	4.80x10^{10}	1.35x10^{11}

30-Month Mars Mission	Φ_{30} by each segment: Transits 12-month	Mars stay 18-month	Total 30-month	Φ_{30} by fraction to 30-month mission: Transits 12-month	Mars stay 18-month*	Total 30-month
Median	2.78x10^8	2.03x10^9	2.34x10^9	2.10x10^9	3.16x10^9	5.26x10^9
Upper 95%	2.16x10^{10}	7.50x10^{10}	9.66x10^{10}	5.40x10^{10}	8.10x10^{10}	1.35x10^{11}

*Organ dose estimates using SPE fluences proportional to the simulated fluence of 30-month mission.

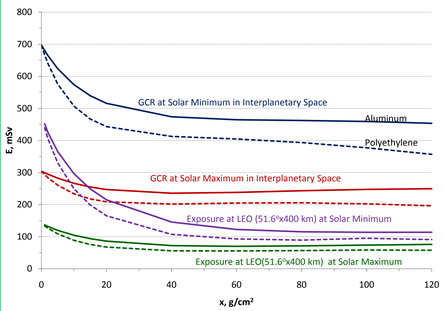
Vertical Distribution of Mars Atmospheric Properties*

Altitude, km	T, °C	p, kPa	ρ, g/cm^3	Atmospheric shielding thickness, g/cm^2: Low density model	High density model
8.0	-41.2	0.34	7.64×10^{-6}	0.14	0.19
6.0	-37.0	0.41	8.98×10^{-6}	3.16	4.34
4.0	-35.0	0.49	1.07×10^{-5}	6.73	9.25
2.0	-33.0	0.58	1.27×10^{-5}	10.97	15.08
0.0	-31.0	0.7	1.50×10^{-5}	16.00	22.00
-2.0	-29.0	0.84	1.78×10^{-5}	19.04	26.17
-4.0	-27.0	1.00	2.12×10^{-5}	22.64	31.13
-6.0	-25.0	1.2	2.52×10^{-5}	26.92	37.01
-8.0	-23.0	1.44	2.99×10^{-5}	32.00	44.00

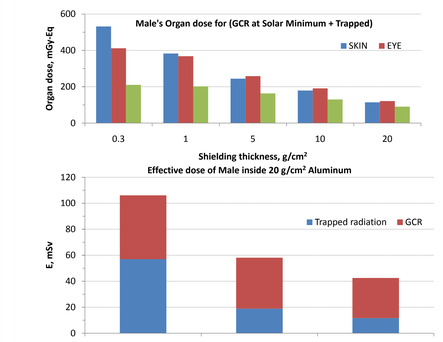
*Temperature and pressure data based on Mars Global Surveyor

Exposure Limit and Acute Radiation Risk Analysis for Mission Scenarios

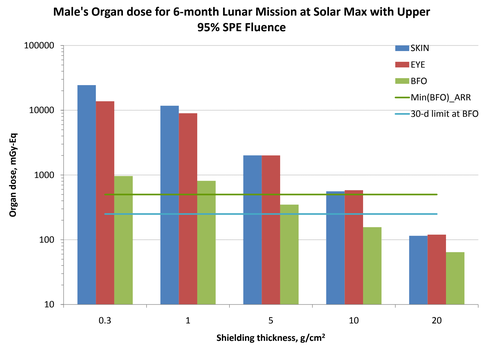
Annual Effective Dose Comparison

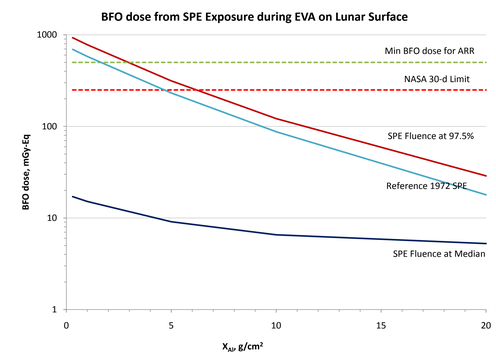


6-month LEO Mission at 51.6°×400 km

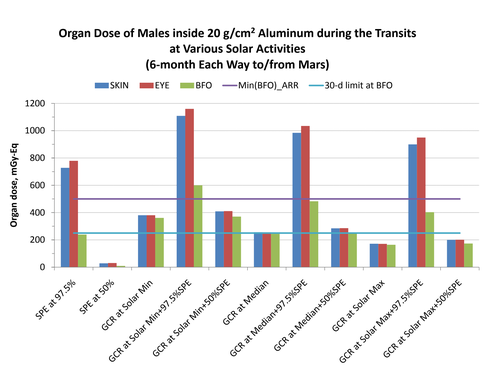


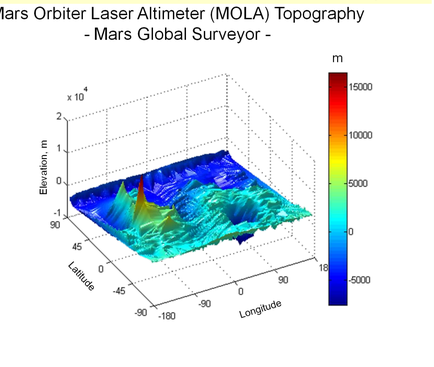
6-month Lunar Mission

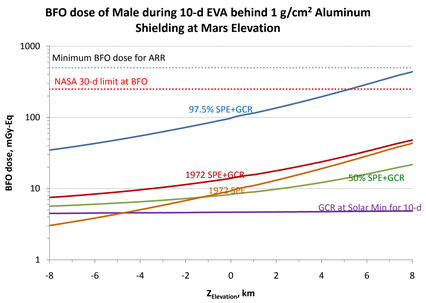


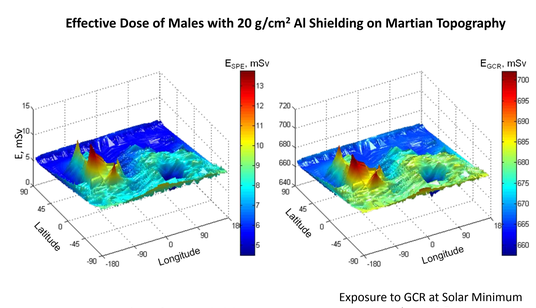


30-month Lunar Mission (6-month transit – 18-month Mars stay – 6-month transit)









Exposure to the Reference 1972 SPE

Exposure to GCR at Solar Minimum during 1.5-yr Martian Surface Mission